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PSYCHOLOGICAL ASPECTS OF THE HUMAN-OPERATOR'S ACTIVITY WHILE TRACKING

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(PSIKHOLOGICHESKAYA STRUKTURA DEYATEL'NOSTI OPERATORA V REZHIME SLEZHENIYA)

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AUTHOR'S SUMMARY

This paper proves the importance of studying the problem of tracking. A conclusion is substantiated about the regulatory role of the dynamic image of processes (objects) when forming control movements in tracking operations. Some concepts are introduced by the author which reflect specific characteristics of the dynamic image. A general substantiation and formulation is given of the concept of formation and decay of the dynamic image. Some essential characteristics of the formulation and decay of the dynamic image are revealed in case of multi-dimensional tracking.

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LIST OF CONTENTS

		Page
1	THE IMPORTANCE OF THE STUDY OF TRACKING PROBLEMS	3
2	THE ROLE OF THE DYNAMIC IMAGE IN THE PROCESS OF TRACKING	4
3	CERTAIN CONCEPTS REFLECTING THE SPECIFIC FEATURES OF DYNAMIC IMAGES	5
4	THE BASIS OF CONCEPTS OF FORMATION AND DECAY OF THE DYNAMIC IMAGE	7
5	THE DETERMINATION OF WEIGHTS FOR THE REFLECTED CONSTANTS OF INPUT SIGNALS IN THE FORMATION OF A DYNAMIC IMAGE	10
6	SPECIAL FEATURES OF THE FORMATION AND DECAY OF THE DYNAMIC IMAGE FOR MULTI-DIMENSIONAL TRACKING	11
References		13
Illustrations		Figures 1 & 2

LT 1979

1 THE IMPORTANCE OF THE STUDY OF TRACKING PROBLEMS

In this article, results are presented of investigations over many years into the activity of operators in a tracking regime, realised on the basis of a dynamic image. The concept formulated of the dynamic image in a tracking regime reveals itself in mechanisms of the formation and decay of this image.

The activity of the human operator in a tracking regime has long attracted the attention of psychologists, physiologists and engineers. As an example, the work of man in a tracking regime may be taken, to show more clearly the specific nature of the psychological control of actions. In addition to this, the study of this work makes it possible to evaluate its possibilities, characteristics and particular features as a specific link in the system by the creation of various control systems and regulating arrangements involving the carrying out of tracking functions by man.

The solution of the problem of the type of tracking to be followed imposes high demands on man; the dynamics of the input signal requires uninterrupted regulation of the controlling motor actions in accordance with the variable components of the signal. Tracking therefore emerges as a dynamic process of visual-motor coordination.

The psychological analysis of the activity of operators of various systems indicates that the initial and essential component of the structure of the activity is the tracking of the course of the events, and of the state of, controlling systems. Moreover, tracking often comes down to the problem of spatial coincidence (seeking or holding) of two signals in independent frames of reference, one of which is defined by factors independent of the operator and by a variable function (random or determined according to established principles), while the other is used by the operator for control[4].

The large number of the variables in tracking problems determines their variety: the discrete or continuous character of the initial trackable signals pursuit or compensatory tracking, the difference in modality of the input signals the difference in the particular features of the dynamics of the system, and so on. On the subject of the forms of tracking, it may be observed that, in compensatory tracking, a person receives information only concerning errors, while, in pursuit tracking, he knows, in addition, what arrives at the input of the system, and what occurs at its output. Accordingly, the functions of man in the two forms of tracking are found to be different.

At the present time, the investigation of tracking has ceased to be a matter for a narrow circle of specialists. This points also to a broadening of

the very understanding of tracking. It denotes not only special cases of the control of the separate characteristics of an object but also the more general problems of control of complex systems.

According to our findings, tracking is an adequate reflection of the relevant information fed in on the basis of its present meaning (for stochastic input information) or of a dynamic image (for determined input information).

2 THE ROLE OF THE DYNAMIC IMAGE IN THE PROCESS OF TRACKING

On the basis of ontogenetic and functional-genetic investigations, A. V. Zaporozhets[3] came to the conclusion that, in the traditional investigations of executive activity, including the study of motor performance quite inadequate attention has been devoted to the role of psychic reflection, and accordingly, in our view perfectly correctly, placed the accent in investigations of these processes on the problem of the genesis, function and structure of those subjective images with the help of which the control of human behaviour is accomplished. The most important condition for the production and development of voluntary movements and actions is the formation of an image of the situation and of those actions which have to be carried out in this situation. According to the theory of N.A. Bernstein[2], the decisive factor in the creation and formation of the macroprogramme of a motive action is the image or representation of the result of the action. The author of this concept emphasises the need for psychological investigations which should not avoid the problem of the formation of an image emerging in the function of a regulator of voluntary motive action. On the subject of reflex movements and habits, N.A. Bernstein wrote: "Those who regard habitual movements as some sort of kinesthetic stereotypes are gravely mistaken"[1]. To plan a motive task means to create in some form or other an image of what is not yet, but ought to be.

B.F. Lomov emphasises that the investigation of problems of operator activity requires the analysis of the process and mechanism of the formation, by the operator, of images of the future state of the object of control; it also requires the discovery of the way in which signals concerning the current state of the object relate to this image and in which controlling actions are organised and regulated, and so on[6].

The analysis which we carried out of much experimental material concerning operator activity in a tracking regime (for laboratory test conditions and real objects), taking different input signals, under various conditions (including experimental ones), "in the dark" (upon disappearance of input information), and so on, leads to the conclusion that a controlling part is played by the dynamic image when tracking operations are carried out.

The dynamic images (DI) are the images of a space-time structure, with the help of which the course of tracking processes is reproduced within an internally subjective period of time. Accurate (synchronous) tracking can be achieved when the time development of the DI proceeds on the basis of the preliminary reflection of the dynamics of the process being tracked, which makes it possible to compensate for delays dependent on the perceptual-motor system and on the dynamics of the object under control.

The preliminary reflection determines one of the most important characteristics of the operator - the ability to foresee the course of controllable events, due to which the operator has the opportunity on the one hand to forestall the appearance of undesirable situations, and on the other hand to react adequately and in good time to these or those circumstances as they arise. The foreseeing of the course of events is essentially the preliminary reflection of them in the consciousness in the form of dynamic images. Upon such reflection, the DI is transformed in the advance of the real dynamics of the object.

In cases where the process proceeds according to established principles, in the DI is reflected a multitude of states mingling with each other in definite time sequence. Although in operator practice, the dynamics of the controlled process is associated with the system of appropriate acts of control, in the dynamic image these acts are associated with appropriate states of the process. Because of this, the anticipation of this or that state of the process becomes a stimulus for the opportune actualisation of the mechanism of the relevant motor reaction to that state. The common preliminary reflection of the states of the process and of reactions related to them ensures the direct transition from the reflection of the dynamics of the process to the preparation and realisation of the necessary controlling actions.

An excellent example of the activity of operators on the DI principle is tracking, with extrapolation, of moving targets. We speak here of extrapolation in cases where, in the process of tracking, for one reason or another, the information from the target ceases to reach the operator and he begins to be guided in his actions exclusively by the DI of the moving target composed in his consciousness when tracking targets in the pre-extrapolation period.

3 CERTAIN CONCEPTS REFLECTING THE SPECIFIC FEATURES OF DYNAMIC IMAGES

The dynamic image is the reflection of a determined sequence of coordinates (or parameters) of the process being controlled, related to fixed values (or to values close to these) of time. For example, one may have the reflections of parameters of technological processes, of the flight trajectory of an aircraft, and so on.

In speaking of DIs, it should be borne in mind that it is impossible to examine, in isolation, the reflection of the coordinates of the process $(x_1 \pm \Delta x_1; y_1 \pm \Delta y_1; z_1 \pm \Delta z_1 \ldots. x_n \pm \Delta x_n; y_n \pm \Delta y_n; z_n \pm \Delta z_n)$ from a reflection of the time sequence $(t_1 \pm \Delta t_1; \ldots t_n \pm \Delta t_n)$, to each value of which, in its turn, corresponds a unique combination of the coordinates of the process, (Fig 1). Thus, for example, when tracking, with the support of dynamic images, targets moving along a sinusoidal trajectory, for each fixed value of the time sequence there must be a corresponding definite value of the amplitude, velocity and acceleration. In this way, the dynamic image of the process (object) in general represents the determined sequence of its space-time coordinates. The DI operates up to the moment of time when the changes in the deviations of its coordinates $(\pm \Delta x_1; \pm \Delta y_1; \pm \Delta z_1 \ldots. \pm \Delta x_n; \Delta y_n; \pm \Delta_n)$ exceed acceptable concrete values relative to fixed moments in the time sequence, the deviations of which $(\pm \Delta t_i \ldots \pm \Delta t_n)$, in their turn, must not exceed acceptable values relative to the coordinates of the process.

We also established experimentally and have given definitions of the time of the process of decay, and of the DIs of strategies and separate phases, in terms of space-time development, for the process being tracked.

<u>Time of the process of decay</u>: This is the time at the expiry of which the deviations of the space-time coordinates of the referred process exceed the maximum permissible value, relative to the reference process. The coefficient of decay then is equal to unity. Thus, for example, in the attack on an aerial target by a fighter, the maximum permissible deviation between the referred and reference processes is 180° out of phase which corresponds to a movement of the target upwards and of the fighter downwards (or vice versa).

<u>DI of the delaying (or advancing) strategy</u> is the space-time development of changes in the parameters of the referred process, delaying (or advancing) relative to the space-time development of changes in the parameters of the reference process.

<u>The DI of mixed strategy</u> is characterised by the fact that, during one part of the process, the decay has the character of a delaying strategy, while, during another part, an advancing strategy is established (no matter in which order).

<u>The phase of decay</u> (or formation) is that element of the space-time development of the DI the completion of which is marked by an increase (or decrease) in the coefficient of decay.

The phase of stabilisation is that element of the space-time development of the DI over which there is no change in the coefficient of decay.

4 THE BASIS OF CONCEPTS OF FORMATION AND DECAY OF THE DYNAMIC IMAGE

Method On the screen of a double-beam oscilloscope, the diameter of which was 150 mm, under the effect of a sinusoidal voltage of 0.3 Hz, a target point (T) and an indicator point (I) were displaced in an upwards-downwards direction by 50 mm; the positions of the indicator was determined by the displacement of the control (pilot's stick) under investigation. The displacement of the target had a static constant amplitude and dynamic constants - speed and acceleration.

The distance of subjects from the screen was 800 mm. The screen was located in the central visual field. The formation of the DI of the process was achieved in 40 s, this time being optimal from the point of view of the period of decay (of the functioning) of the DI[5]. The subjects, in accordance with instructions received, blended the I with the T by action on the control. With expiry of the period of formation, T and I disappeared simultaneously from the screen. The investigators continued tracking on the basis of the dynamic image they had previously formed. The trajectories of movement of T and I throughout the experiment were recorded by loop oscilloscope. 317 male subjects, aged from 18 to 21 years, took part in the experiments.

On the basis of the analysis of experimental material, tests were undertaken to determine the mechanism of formation and decay of the DI. It was discovered that, for operators working in a regime of tracking with extrapolation, the processes of formation and decay of the DI are continuous, and are interdependent on and determined by each other.

The analysis of the oscilloscope recording showed that the process of formation of the DI consists of three stages. Individual fragments of the tracking during each of these stages reflect the special features of the dynamics of the formation process (Fig 2).

In the first stage, the operators strive, in the main, to solve the overall problem, the minimisation of the value of the visually represented error between the instantaneous positions of T and I, *ie* the aim of the tracking is achieved. Thereupon, the static constant of the input signal, the amplitude, is, above all, recorded. Controlling actions bear a discrete character, *ie* operators work in a regime of compensatory tracking (as in the case of tracking random input signals).

In the second stage, operators record the mean velocity of movement of T4, and relate the position of I to T to the velocity of movement and to the angular position of the arm, *ie* they begin to form the kinesthetic feedback. Thereupon, whereas the visual component of the feedback arises immediately in the tracking process, the kinesthetic component begins to form only with the perception of the dynamic constants of the moving target, *ie* of the parameters of the input signals. By virtue of this, rearrangement of the visual image occurs, creating conditions for the activation of the internal control loop (kinesthetic analyser - motive apparatus of the arm).

In the third stage, the operators continually record the dynamic constants of the target, the velocity and acceleration. This corresponds to the continuous formation of the kinesthetic feedback. At the same time, the value of the visual feedback lessens and consequently, the significance of the error of mismatching decreases. A condition of the effective inclusion of the kinesthetic feedback is the visual forecasting of changes in the position of the target and the finding of physical measurements of movement.

In this stage, the parameters of movement of the arm become adequate as parameters of the displacement of T. Operators are found to be capable of compensating for delays inherent in the nervous-mental system of man and in the object of control, in such a way as to produce, at the output of the process a repeating control function without any lag and even with a certain advance. This regime is realised with the help of the time development of dynamic images. The process of forecasting is, by its nature, one of advance reflection.

The most important factor where the regime of forecasting is concerned is the possibility of producing future states of an input signal. As the knowledge of the structure of the input signal increases, the operator works as a synchronous generator, the output signal of which coincides in phase with the input signal. His behaviour resembles that of an open system operating according to a previously prepared programme. Thereupon, errors in the tracking of the input signal decrease. In this stage, the process of formation of the DI is completed. Thus, the DI of the multi-component input signals arises as the result of the rather prolonged interaction with them under conditions of objective activity.

In the process of the formation of the DI, two levels of reflection are involved, combining in a definite degree the logical and sensory, the perceptual and cognitive.

The formation of the DI ends with the successive reflection of constants of the 'input' information (input signals) in hierarchical order from top to

bottom, *ie* initially the overall tracking problem is solved, then follows the detailing and adequate reflection of all components of the structure of the process.

From the point of view of information links, where the dynamic image of T is concerned, the structural scheme is found to be an open one, while, as regards the dynamic image of I, this scheme remains closed by reason of the kinesthetic feedback. The system of kinesthetic signals arising from partial movements emerges as one of the most important mechanisms by which time parameters are introduced into the control process and this is of great significance for the control of arm movements where the duration, amplitude, velocity, acceleration, correct sequence, complete realisation, corrective movements and pauses are concerned. Consequently, the dynamic image of I is considerably more stable than that of the T, and acts as a natural support permitting the target's dynamic image to operate for longer periods.

In our opinion, the targets dynamic image is, to a definite extent, supported by the indicator's dynamic image and by a certain mean disparity (between T and I in the process of formation) which, according to data obtained for a considerable contingent of subjects (more than 300 persons), is represented by a constant value.

The analysis of the time development of the decay of the DI shows that it consists of two successive stages: a transitional and a stationary one. In the course of the transition stage, in practice the static and dynamic constants of the input signals - amplitude, velocity, acceleration - are fully maintained. In the stationary stage, maintenance is observed of the static constants, and generalisation of dynamic ones occurs, *ie* the tracking, effected on the basis of the DI, proceeds with a certain constant mean velocity. Thereupon, in the DI there is produced the complete erasure of acceleration and deformation of the velocity of the control process.

In this way, in the process of decay of the DI one observes its structural depletion; certain structural shadings (structural details) are lost. Thus, the generalised velocity of movement of I in the stationary stage is distinct from the true velocity of T; in the process of decay of the DI, this gives rise to an accumulation of errors of mismatching, mainly as regards phase, and the surpassing of a maximum permissible value of this error leads, in the final analysis, to the total decay of the dynamic image. The amplitude for one-dimensional tracking with support from the DI is reflected accurately in practice by insignificant variations relative to given values.

LT 1979

In the process of decay of the DI, as in the process of its formation, all levels of reflection, including the level of the outer (cortical) layer, take part. This confirms the fact established by us that, in the case of simultaneous completion of a tracking process with support from the DI and solution of mental problems, the time of the process of decay is shortened by 64%.

In this way, the process of decay of the DI concludes in the erasure of reflected constants of the input information (input signals) in hierarchical order from bottom to top; first the dynamic components of higher orders are erased, and then the tracking is completed with a certain generalised constant speed.

5 THE DETERMINATION OF WEIGHTS FOR THE REFLECTED CONSTANTS OF INPUT SIGNALS IN THE FORMATION OF A DYNAMIC IMAGE

We established earlier that the efficiency of tracking determined input signals of different structures varies[4].

The input signals investigated have different numbers of constants (components): square-wave signals have the amplitude, sawtooth ones amplitude and constant velocity, sinusoidal ones the amplitude and regularly varying velocity and acceleration.

The method which we developed for the successive elimination of constants of input signals makes it possible to determine their weight in the process of formation of the DI. As *a priori* data we used experimentally determined integral errors of tracking sinusoidal, saw-tooth and square-wave signals in the process of DI formation, equal to F_1, F_2, F_3 respectively.

Since opportunities for the operator in the process of DI formation are in practice limited by the perception of amplitude, velocity and acceleration of the moving object, then it is sensible to take the relative accuracy of tracking sinusoidal signals as being equal to unity, *ie*

$$K_A + K_v + K_a = 1$$

where K_A = the coefficient of accuracy for the perception of the amplitude;

K_v = the coefficient of accuracy for the perception of the velocity;

K_a = the coefficient of accuracy for the perception of the acceleration.

The relative values of the accuracy for tracking sinusoidal, saw-tooth and square-wave signals in the process of DI formation are respectively:

$$F_1' = 1; \quad F_2' = \frac{F_1}{F_2}; \quad F_3' = \frac{F_2}{F_3},$$

whence $F_1' = K_A + K_V + K_a$;

$F_2' = K_A + K_V$;

$F_3' = K_A$.

Consequently,

$$K_A = F_3'; \quad K_V = F_2' - F_3'; \quad K_a = F_1' - F_2'.$$

In the frequency range of input signals, 0.1 - 0.5 Hz, which we investigated, the mathematical expectations of the coefficients of accuracy for perception of the amplitude, velocity and acceleration in the process of formation are respectively:

$$K_A = 0.33; \quad K_V = 0.52; \quad K_a = 0.15.$$

When signals change to ones of more complex structure in the process of DI formation, one uses a larger alphabet and builds a structurally enriched image.

Consequently, in the process of DI formation, perceptible constants of input signals fulfil the role of information sources having different weight values.

6 SPECIAL FEATURES OF THE FORMATION AND DECAY OF THE DYNAMIC IMAGE FOR MULTI-DIMENSIONAL TRACKING

Method During the 40 s, subjects tracked the target, which was travelling over the screen of the oscilloscope along a circular trajectory of 25 mm in radius. The displacement of I was achieved by the action of the right hand on the control (pilot's stick), which, like the object of control, (in our case I), possessed similar dynamics (equivalent to an amplifying link) in the horizontal and vertical planes. The organ of control was displaced in a horizontal plane in a circle of 95 mm in radius. The period of displacement of the T in a circular path was 3.3 s, corresponding to a linear velocity of 47 mm/s. According to instructions, the subjects continued tracking even after the disappearance of T and I from the screen, *ie* on the basis of the DI of the process formed. The trajectories of movement of the TM and TB were recorded by a loop oscilloscope.

LP 1979

Instantaneous positions of I along a given trajectory relative to T were unambiguously defined by the horizontal and vertical coordinates and also by the displacement phase, the value of which depended on the ratio of the velocities of movement of I and T . The phase is determined by the reflection strategy (advancing or retarding). The nature of the reflection of the coordinates referred to earlier is determined by the special features of the formation and decay of the DI.

In the process of DI formation, the reflection of vertical coordinates occurs with overestimation; horizontal coordinates are reflected with under-estimation. The reflection of vertical coordinates is achieved more accurately than that of horizontal coordinates. The strategy determined by the sign of the phase bears a retarding character.

In the process of decay of the DI, the character of the reflection of vertical and horizontal coordinates remains the same as for the formation process. The strategy is a mixed one - initially retarding, then advancing.

For the evaluation of the time process of decay of the DI, we introduced the concept of amplitude-phase integrity of the DI structure. The amplitude integrity is determined by the character of the reflection of the coordinates and is maintained until the moment when the deviation of the vertical and horizontal coordinates exceeds a maximum permissible value. The phase integrity is determined as in the case of one-dimensional tracking.

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Figs 1&2

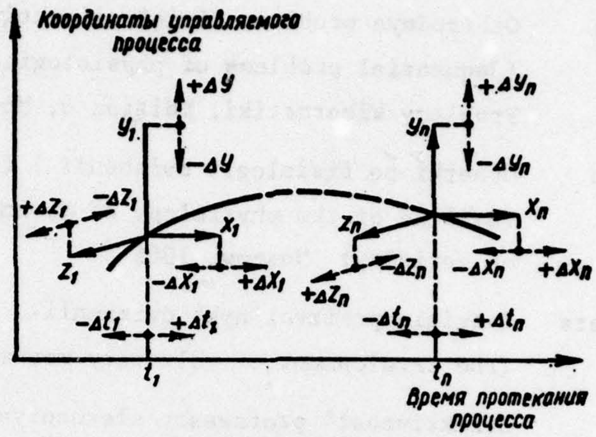

Fig 1 The scheme of the space-time development of the dynamic image of the process being controlled

Along the abscissa: time for which the process has continued;

Along the ordinate: spatial coordinates of the controlled process

Fig 2 Stages in the formation of the dynamic image (from left to right: stages I to III)

——— trajectory of T

------ trajectory of $\underline{\mathrm{T}}$

LT 1979

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